TITLE: AN ARTICLE IDENTIFICATION TAG, AND A METHOD FOR THE DETECTION THEREOF

Technical Field

The present invention relates to article identification tags and the detection thereof. More particularly, the invention relates to article identification tags having a plurality of electrically conductive members. The invention also relates to a method of detecting such an article identification tag.

Prior Art

Many applications require a reliable and contactless detection of the presence, identity or position of objects within a detection zone. Common examples are for instance price labeling of commercial articles, identification of components in production lines, identification of material type at recycling plants or electronic article surveillance in e.g. shops.

For some applications it is sufficient to detect the presence of the object or article. One example is a simple electronic article surveillance system, which is arranged to provide an alarm signal, once a protected article is carried into a detection zone. Such a simple application uses a tag having one single sensor element in the form of a thin metal strip or wire with magnetic properties. The sensor element may be detected magnetically by means of arc-shaped magnetic generators/detectors, which expose the sensor element to an alternating magnetic field, that affects a physical property of the sensor element. Use is often made of the fact that the alternating magnetic field causes a periodical switch of the magnetic momentum of dipole of the sensor element, which is also known as Barkhausen jumps. Tags of this kind are for instance disclosed in US-A-5 496 611, EP-A-0 710 923 and EP-A-0 716 393.

A different single-element tag technology is described in WO97/29463 and WO97/29464, wherein each tag comprises a wire-shaped element of amorphous or nano-crystalline metal alloy. An important feature of the amorphous or nano-crystalline metal alloy is that the permeability thereof may be controlled by an alternating magnetic modulating field. Through a physical effect known as Giant Magnetoimpedance, the amplitude of an electromagnetic reply signal from the tag is modulated by the magnetic modulating field, when the tag is excited by an electromagnetic interrogation signal. The modulation in amplitude of the reply signal is detected and used for determining the presence of the tag in the detection zone. A similar application is shown in WO98/36393, where very thin amorphous or nano-crystalline wires are used as sensor elements. These wires (also known as microwires) have a diameter of less than 30 μm, preferably 5-15 μm.

None of the electronic article surveillance applications described above provides a remotely detectable identity for each tag. However, for advanced applications it is necessary to provide such identity information, representing e.g. an article number, serial number, material code, etc., for the respective object, to which each tag is attached. In a different technical field, such identity information is provided by barcodes (such as EAN), i.e. a printed pattern of black and white lines, which is scanned by an optical reader. Optical barcode tags have an advantage in that they offer a wide codespan - an EAN barcode may for instance represent a 12-digit article number, thereby theoretically providing a codespan of 10^{12} different barcode values. Optical article identification systems have a distinct drawback, however, in that the operating distance thereof is quite restricted; the barcode tag will have to pass in close proximity with the optical reader for allowing a successful reading of the

barcode. Furthermore, since the barcode is read by optical means, the tag must be attached to a visible surface portion of the article in question.

A non-optical system with longer operating range is disclosed in WO88/01427, wherein the tag or marker is provided with a number of sensor elements in the form of magnetostrictive strips or ribbons made of an amorphous ferromagnetic material and arranged in predetermined angular relationships or at predetermined distances from each other. The identity of such a tag is represented by the predetermined relationships as well as the respective type of individual sensor elements. The sensor elements are excitable to mechanical resonance by magnetic energy. The magnetic signals generated by the resonating sensor elements may be detected magnetically or inductively. Compared to optical barcode systems, the tag of WO88/01427 provides a significantly more limited codespan.

A similar system is described in WO93/14478, wherein the tag or markers are provided with a number of electrical resonant circuits, each of which is inductively coupled to a respective magnetic sensor element. Each electrical resonant circuit is excited to oscillate electrically, and the resonant frequency thereof is controllable, through the permeability of the magnetic element, by an external magnetic field, wherein a simultaneous detection of several identical tags is made possible.

In summary, prior art tags for remote non-optical detection of objects are either of a single-element type, allowing only the presence of each tag to be detected, or of a multi-element type, allowing also an identity of each tag to be detected. Single-element tags are easier to design and produce and therefore have a lower unit cost. On the other hand, multi-element tags require a supporting carrier (particularly for mechanically resonating sensor

elements) and/or capacitive and inductive components (for the electric resonant circuit versions). Naturally, this implies a higher cost per unit. Furthermore, the codespan (number of different code values) of the multi-element tags described above is clearly inferior in comparison with optical barcode tags. Additionally, since the multi-element tags mainly operate by magnetic or inductive link, the operating distance of the detection system is quite narrow (although better than for optical barcode systems).

US-A-4 350 883 discloses a method of detecting an article identification tag having a plurality of metallic wires. Each metallic wire is selected from a range of specimens of different electric conductivity or, possibly, different magnetic permeability. The metallic wires are used as marking or coding elements to represent the code or identity of the tag. When detecting the tag in US-A-4 350 883, the wires are exposed to a high-frequency electromagnetic field, the frequency of which is varied either between two distinct frequencies or continuously. A variation in a corresponding response signal is picked up.

Summary of the Invention

Therefore, an object of the present invention is to provide an article identification tag at a considerably lower cost than previously known tags. More specifically, the invention aims at providing a tag, which combines the good characteristics of optical barcode tags (large code span) and non-optical multi-element tags (long operating distance) at a very low price per tag.

It is a further object of the invention to provide a method of detecting an article identification tag according to the above.

The objects of the invention have been achieved through the inventive understanding that basically any electrically conductive material can be used as material for the sensor elements of the tag, thanks to the novel detection method according to one aspect of the invention. For instance, a piece of copper or aluminium wire will make an excellent tag. Alternatively, magnetic materials such as simple iron or steel wires may be used.

The objects of the invention are achieved by the appended independent patent claims. Other objects, features and advantages of the present invention will also appear from the following detailed disclosure, from the drawings as well as from the subclaims.

Brief Description of the Drawings

The present invention will now be described in more detail, reference being made to the accompanying drawings, in which:

FIG 1 illustrates an article identification system, in which the method and the tag according to the present invention may be applied,

FIGs 2 and 3 are diagrams illustrating the physical basis behind the method according to the present invention, and

FIGs 4-7 are schematic illustrations of different exemplifying embodiments of a tag according to the invention.

Detailed Disclosure of the Invention

FIG 1 illustrates an article identification system for detecting a tag 30 attached to an object 20, and for determining an identity thereof. A system similar to the one illustrated in FIG 1 is thoroughly disclosed in WO 97/29463, WO 97/29464 and WO 98/36393, all of which are fully incorporated herein by reference. A transmitter antenna 11 and a receiver antenna 12 are arranged in a detection zone 10. The transmitter antenna 11 is operatively connected to an output stage 13, which in turn is connected to a controller 14. The output stage comprises various commercially available driving and amplifying circuits and means for generating an alternating electric current of high frequency f_{HF}, said current flowing back and forth through the transmitter antenna 11 when supplied thereto, wherein a high-frequency electromagnetic field is generated around the transmitter antenna. This electromagnetic field is used, as will be described in more detail below, for exciting the tag 30 within the detection zone 10, so that the tag will transmit, at the reception of a first electromagnetic

signal 50 from the transmitter antenna 11, a second electromagnetic signal 60, which is received by the receiver antenna 12 and transformed into a corresponding electric signal 70.

The receiver antenna 12 is operatively connected to an input stage 15, which comprises conventional means with amplifying and signal processing functions, such as band-pass filtering and amplifying circuits. The input stage 15 also comprises means for demodulating the received signal 70 and supplying it, as a reply signal 80, to the controller 14.

The transmitter antenna 11 as well as the receiver antenna 12 thus have the purpose of converting, in a known way, between an electrical signal of high frequency and an electromagnetic signal. Preferably, the antennas are helically formed antennas with rotating polarization (for optimal coverage in all directions), or alternatively conventional end-fed or center-fed halfwave whip antennas, but other known antenna types are equally possible.

The detection zone 10 may optionally be provided with means 16, such as a coil, for generating a magnetic modulating field H_{mod}. The means 16 is connected to the controller 14 via a driving stage 17. The driving stage 17 comprises means for generating a modulating current, which is supplied to the means 16, wherein the magnetic modulating field H_{mod} is generated in essential portions of the detection zone 10. The magnetic modulating field H_{mod} may have a frequency of about 500-800 Hz, and the electromagnetic excitation and reply signals may have a frequency within the GHz band, such as 1.3 GHz or 2.45 GHz. Frequencies outside these ranges are however also possible.

As described above, the object 20, which has been schematically illustrated in FIG 1 in the form of a box-shaped package, is provided with the tag 30 according to the invention, comprising a number of electrically

conductive members 31-3n (FIG 4), which provide an identity of the tag 30, or of the object 20 to which the tag is attached, as will be described in more detail below.

The members 31-3n are electromagnetically detectable. Optionally, if a means 16 is used as in FIG 1 for generating a magnetic modulating field H_{mod}, the members 31-3n may comprise a magnetic material, the permeability of which is controllable by a magnetic field and the high-frequency impedance of which depends on said permeability, according to an effect commonly known as Gigant Magneto-Impedance. This effect causes a modulation in amplitude of the second electromagnetic signal 60 transmitted from the tag 30 and received by the receiver antenna 12 as the signal 70. The amplitude is modulated by the magnetic modulating field H_{mod}.

The detection method according to the present invention will now be described with reference to FIGs 2 and 3. The method according to the invention is based on novel use of a skin-depth phenomenon known per se, which occurs for high-frequency electrical signals in electrical conductors. Skin-depth is a common name for the fact that the conduction of electrical current will only take place in an outer layer or skin layer of the conductor at high frequencies. The penetration depth is related to the signal frequency as well as the electrical resistivity and magnetic permeability of the conductor.

An electrically conductive member 1, such as an arbitrary one of the members 31-3n (FIG 4) of the sensor 30 indicated in FIG 1, is illustrated in cross-section in FIG 2. The electrically conductive member 1 has a radius R and a skin-depth d, which according to the above varies with the signal frequency. Therefore, the effective impedance R_{eff} (FIG 3) of the electrically conductive member 1 is related to the skin-layer cross-sectional area S, i.e. the

area where the electrical currents are conducted at the signal frequency in question. More specifically, the effective conductor impedance $R_{eff} = S \cdot \rho_{conductor}$, where $\rho_{conductor}$ is the electrical resistivity of the member 1. Since the skin-layer cross-sectional area S will depend on the skin-depth d, which in turn depends on the signal frequency, the effective conductor impedance R_{eff} will vary with the signal frequency, provided that the signal frequency is not reduced to an extent, where the skin-depth d reaches and equals the radius R of the electrically conductive member 1.

FIG 3 illustrates the effective impedance R_{eff} of the electrically conductive member 1 when exposed to an electromagnetic high-frequency (HF) signal, such as the excitation signal 50 submitted by the transmitter 11 of FIG 1. As long as the HF frequency is high enough (frequency f_1), the effective impedance R_{eff} of the electrically conductive member 1 will have a continuous waveform, as illustrated in the left-most portion of the graph shown in FIG 3. On the other hand, when the HF frequency is reduced to a frequency f_2, where the skin-depth d reaches and equals the radius R of the electrically conductive member 1, the effective impedance R_{eff} of the member 1 will stop to decrease, even if the HF frequency is reduced further. Therefore, a discontinuity point occurs in the relation between effective conductor impedance and HF frequency shown in FIG 3, where d = R. According to the invention, this discontinuity point is used for detecting an article identification tag 30 and/or determining an identity thereof.

Consequently, according to a method of detecting an article identification tag 30 having at least one electrically conductive member 1, the following steps are performed. An alternating electric current is caused to flow through the member 1, for instance by exciting the

member 1 by means of a high-frequency electromagnetic field, such as the excitation signal 50 of the system shown in FIG 1. The frequency of the alternating electric current is varied, and a corresponding variation in impedance is monitored for the member 1. This correspondingly varying impedance may for instance be monitored via the reply signal 60 received by the receiver antenna 12 in FIG 1. Then, a discontinuity is detected in the varying impedance, and the frequency at which this discontinuity appears is detected. By selecting an electrically conductive member 1, which has a predetermined diameter, a predetermined electrical resistivity or a predetermined magnetic permeability, this frequency (at which the discontinuity appears) will also be predetermined and may be used for providing the member 1 with an identity, since the skin-depth thereof depends on all these parameters.

FIG 4 illustrates a first embodiment of a tag 30 according to the invention. The tag 30 comprises n electrically conductive members 31, 32, 33...3n, having respective predetermined diameters ϕ_1-ϕ_n, respective predetermined electrical resistivities ρ_1-ρ_n or respective predetermined magnetic permeabilities μ_{r1}-μ_{rn}. Combinations of these parameters are also possible. Hence, each electrically conductive member 31-3n of the tag 30 will have one of the above predetermined properties, and consequently the frequency at which the discontinuity appears in the reply signal from the tag 30 will also be well-defined. The tag 30 of FIG 4 is particularly well adapted for use in an electromagnetic article surveillance system, such as the one illustrated in FIG 1.

FIG 5 illustrates a second embodiment of a tag 34, having a plurality of interconnected sections with different respective diameters ϕ_1, ϕ_2, ϕ_3 and ϕ_4.

FIGs 6 and 7 illustrate further embodiments of a tag 35, 36, respectively, according to the invention. In FIG 6,

the tag 35 comprises five interconnected members having different respective predetermined diameters, electrical resistivities and/or magnetic permeabilities. In FIG 6, the tag 36 comprises nine different interconnected electrically conductive members.

A simpler tag, comprising only one electrically conductive member, may also be used according to the invention. For instance, considering a standard anti-theft inductive-coupling pedestal system used in many shops, a tag may be used consisting of e.g. a copper wire wound in a single-turn loop. By applying an FM-modulating inductive excitation signal having a frequency deviation, which sweeps past the tag discontinuity frequency, an AM-modulated tag signal will be received in the pick-up coils of the pedestals. This AM modulation results from the change in impedance of the copper wire loop, as its skin-depth changes with the excitation frequency. Starting at the maximum frequency, the AM signal will increase in amplitude, as the frequency decreases and the skin-depth increases. However, at the frequency where the skin-depth reaches the radius of the copper wire, the loop impedance will abruptly cease to decrease, and a plateau (or flat region) will appear in the received AM signal. Such a signal clipping will indicate the presence of the tag in the anti-theft detection zone and will be a criterion for triggering an alarm. In other words, the clipping region represents the frequency interval, during which the skin-depth exceeds the radius of the conductor.

Different electronic or digital signal processing techniques may be utilized to precisely determine the frequency of the amplitude modulation (voltage drop) discontinuity related to the frequency modulation of the applied alternating signal. One such technique involves an amplitude demodulation of the alternating voltage drop

signal, followed by subtraction of the FM reference signal in order to detect the discontinuity point.

One particular advantage of the invention is that the conductor radius detection criterion represents a discontinuity in the measuring signal, which may be easily distinguished from continuously varying features in the measuring signal, resulting from e.g. frequency-related changes in inductance, reflections, capacitive couplings, etc.

As an alternative to solid electrically conductive members, also tubular conductors may be used for article identification tags. Here, the thickness of the tube wall will define the discontinuity point. One such implementation, particularly suitable for e.g. the fashion industry, would be a metallized synthetic fiber. One advantage of a tubular conductor over a solid conductor is that the total volume of conductive material will be larger for the same skin-depth saturation point, thereby providing larger tag signal levels.

The multi-member tag embodiments shown in FIGs 4-7 will assist in reducing the risk of false alarms, since the multi-member tag will be provided with an identity thanks to the predetermined respective diameters, resistivities and/or permeabilities.

Yet another possibility to reduce the risk of false alarms and to add a further information coding parameter is to use non-circular cross-sections e.g. rectangular cross-sections. In such a case, the minimum dimension may be measured by the discontinuity point. For e.g. a rectangular cross-section, the thickness would be measured through the discontinuity point. The width may then be measured by using a secondary effect of the skin-depth, namely that for a certain change in skin-depth (related to a certain change in frequency), the corresponding change in effective impedance will depend on the width.

The electrically member(s) described for the different embodiments above may be given many different shapes, e.g. in the form of wires, strips or ribbons, and may comprise various different materials, such as non-magnetic metals (e.g. copper or aluminium), magnetic metals (e.g. iron), metal alloys (e.g. steel), or alternatively amorphous metal alloys.

The invention has been described above with reference to a few embodiments. However, other embodiments than the ones disclosed are equally possible within the scope of the invention, as is readily realized by a man skilled in the art.